Journal of Information Hiding and Multimedia Signal Processing ©2016 ISSN 2073-4212
Ubiquitous International Volume **7**, Number **3**, May **2016**

An Analysis Model for OFDMA-Based Inter-cell Interference

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Received December, 2015; revised February, 2016

Abstract. *Soft Frequency Reuse (SFR), as a promising method of the inter cell interference coordination, has been proposed by many companies for E-UTRA. The resources allocation is measured by subband in this kind of OFDMA (Orthogonal Frequency Division Multiplexing Access) based system. In this paper, an analysis model for this kind of scheme is proposed. Further, the interference factors in the SFR scheme are analyzed and the calculation formulation of SIR (Signal to Interference Ratio) and throughput for cell edge users and cell inner users are given. Simulation results validate the analysis model.*
Keywords: SFR, OFDMA, Inter-cell interference, Throughput.

1. **Introduction.** In wireless communication, various kinds of interference in the system restrict the enhancement of spectrum utilization, service rate and the coverage range abilities, etc. [1-2]. LTE-Advanced is the evolution version of LTE (Long Term Evolution), which can satisfy the needs of the future wireless communication market with higher demands and more applications [3-5]. The mobile communication network is a real-time changing dynamic network. Along with the future network evolution, many challenges will be introduced in the related works of LTE-Advanced when the personal equipment develop, such as the micro base station, the pico base station, indoor coverage, the relay station and the home base station, etc [6]. In the future wireless system, the distribution of system loads, frequency allocation, power allocation and the interference among systems are all changed. The control and the management abilities to the base station have also been greatly increased.

In order to improve the network performance and meet the needs of LTE, the more effective interference management techniques must be used to solve the interference problem in the future system. Orthogonal frequency division multiplexing (OFDM) technique can guarantee the orthogonality between symbols by using orthogonal sub-carrier [7-8], which effectively solve the problem of interference among symbols. Due to the limited spectrum resources, inter-cell interference (ICI) is inevitable even though the OFDM technology is used, which will seriously affect the cell edge user's rate. Then, how to maximize the spectrum utilization and avoid the mutual interference under the existing limited spectrum resource environment is one of the main problems to be solved. In addition, the multiple antenna technology can be used to improve the cell-inner user's service rate, however, it is difficultly to improve the cell edge user's service rate, which will result the differences larger between the performance of inner cell and edge cell [9]. In the LTE-Advanced system, the interference mainly comes from the users and the base station in adjacent cells.

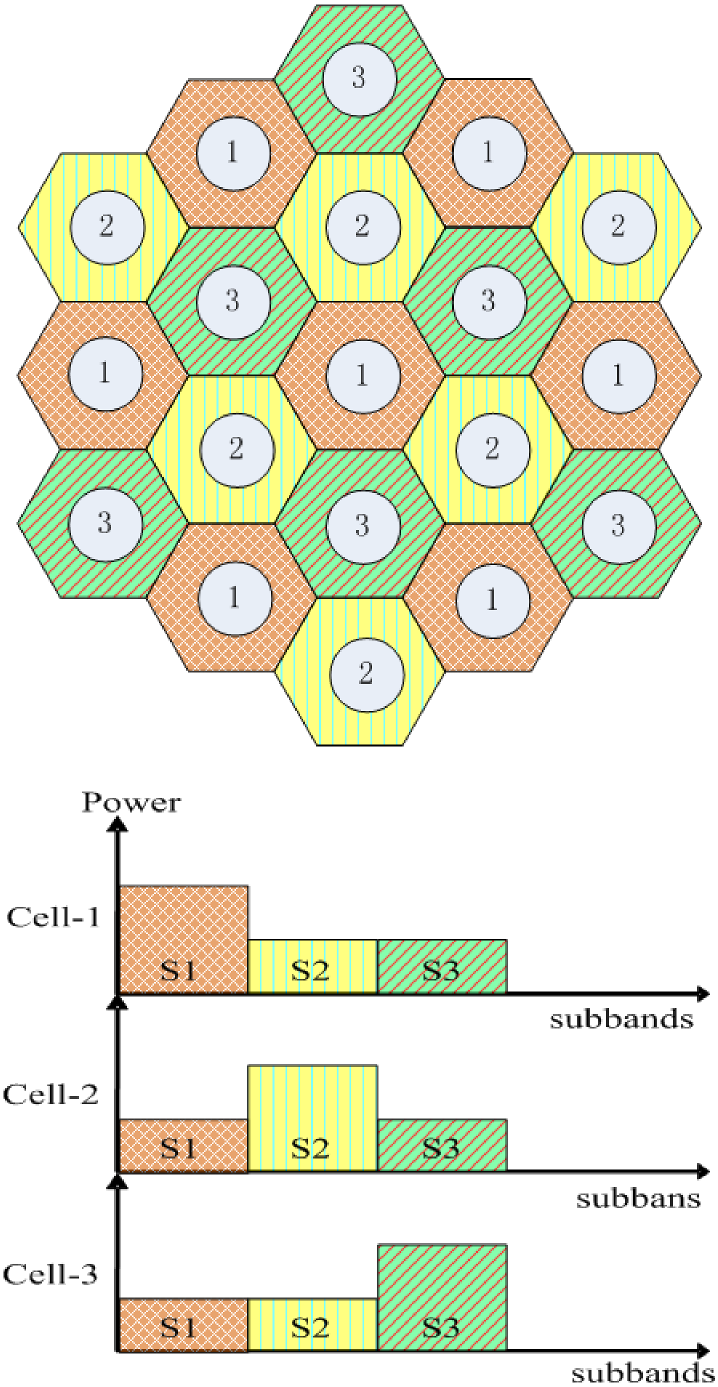

FIGURE 1. SFR scheme in a multi-carrier system

The interference coordination techniques can be used as an important means to ensure the system work stable [10-11]. Several methods have been proposed for ICI management including frequency planning for ICI mitigation [12-13]. The SFR scheme was proposed by Huawei can be used to reduce the inter-cell interference and improve cell edge data rate which mainly utilize two different frequency reuse factor at the inner cell and the edge cell to eliminate the ICI of the cell edge whilst take full advantage of the frequency resource [14-15]. The SFR scheme breaks through the traditional limit of fixed frequency reuse factor, the whole area is divided into two parts: the inner area and the edge area with

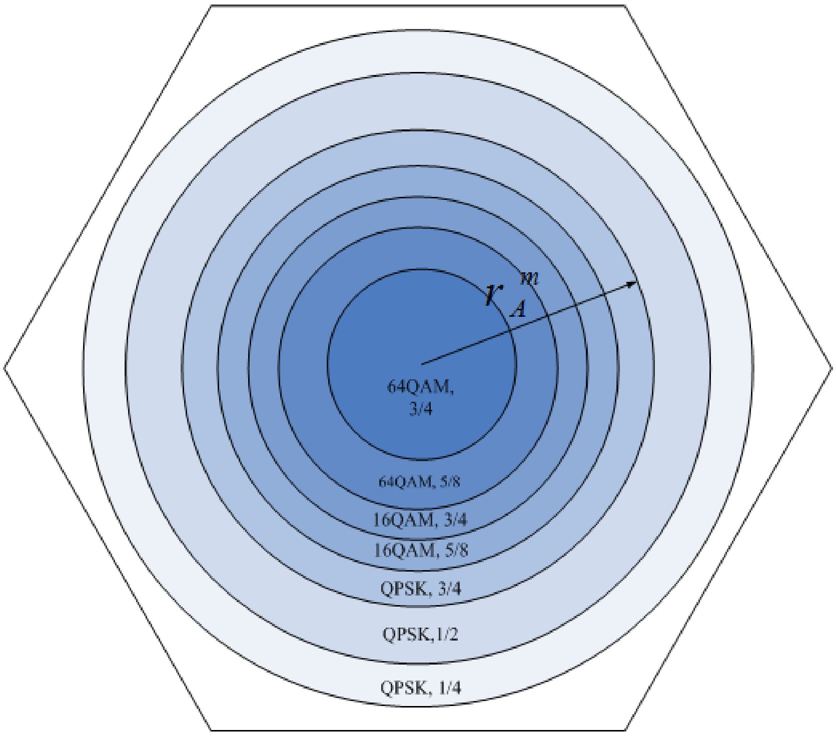

FIGURE 2. SIR Distribution

different frequency reuse factor, which are distinguished by different transmission powers. The higher powers are allocated to the cell edge users and the lower powers are allocated to the cell inner users. The total frequency reuse factor is related to the transmission power ratio of the cell inner users to the cell edge users, which is changed. When it is equal to 0, the system frequency reuse factor is 3, and each cell's available bandwidth is the total bandwidth of 1/3; when it is 1, the system frequency reuse factor is 1, and each cell can use the total bandwidth; when it is between 0 and 1, the frequency reuse factor in the cell inner area and the edge area is different, and the bandwidth can be used by each cell is between 1/3 and 1 of the total bandwidth.

In the system of the traditional fixed frequency reuse factor, the spectrum utilization can be maximized with reuse factor of 1, but the users located at the cell edge may suffer from more serious co-channel interference. While the system with reuse factor of 3 can solve the problem, in which, the spectrum utilization is relatively low. Therefore, the SFR scheme comprehensively consider the cell edge user's co-channel interference and the whole system's spectrum utilization by power control to change the frequency reuse factor K, and let K vary from 1 to 3 [3].

Therefore, in the SFR scheme, the spectrum resource which each cell can use varied with the change of the transmit power ratio of inner users and edge users. The smaller ratio means the greater system soft frequency reuse factor and the smaller co-channel interference, which results the lower spectrum utilization. In another hand, the larger ratio means the smaller system soft frequency reuse factor, which results the higher spectrum utilization, however, the co-channel interference of the cell edge users will be more serious.In practical operation, criterion to rightly judge the CIU (cell inner user) and CEU (cell edge user) is very important to the system throughput (the geometry factor is considered, thereafter call it radius ratio).

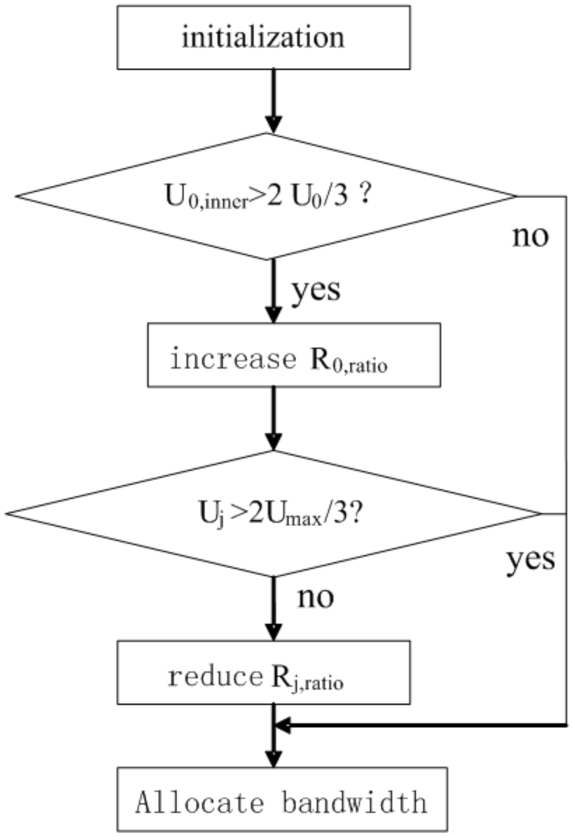

FIGURE 3. Improving the CIU's throughput by modifying radius ratio

In this paper, a model and methodology to analyze the performance of OFDMA based cellular system under soft frequency reuse scheme was illustrated. We analyze the interference factors in the SFR scheme and give the calculation formulation of SIR and throughput for cell edge users and cell inner users. The effectiveness of the analysis model is validated by simulation.

The remainder of the paper is organized as follows. Section II illustrates the network model of the SFR scheme. Section III presents the details of our proposed method. The simulation results are presented in Section IV. Finally, our conclusions of this paper are presented in Section V.

2. **Network Model.** In the following, we will illustrate the spectrum resource allocation mode and the power allocation strategy of the SFR scheme as shown in Fig.1(a). Let S denotes the total sub-band group, which is divided into three sub-band groups respectively as, represented by grain, perpendicular and diagonal, respectively. A subband defined as a frequency resource unit, certain numbers of sub-carriers are loaded in each subband. We assume that each sub-band is continuous. As shown in Fig.1(b), all the CIU use the low transmission power P_{inner}, and all the CEU use the high transmission power P_{edge}.
In the cell tagged as '1', the CIU can use the sub-band groups S_2 and S_3, and the CEU can use the sub-band group S_1. In the cell tagged as '2', the CIU can use the sub-band groups S_1 and S_3, and the CEU can use the sub-band group S_2. In the cell tagged as '3', the CIU can use the sub-band groups S_1 and S_2, and the CEU can use the sub-band group S_3. It is seen that, the sum of the bandwidth which can be used by the three adjacent CEU is equal to the sum of the total bandwidth, and the sum of the bandwidth which can be used by each CIU and CEU is also equal to the total bandwidth. In this paper,

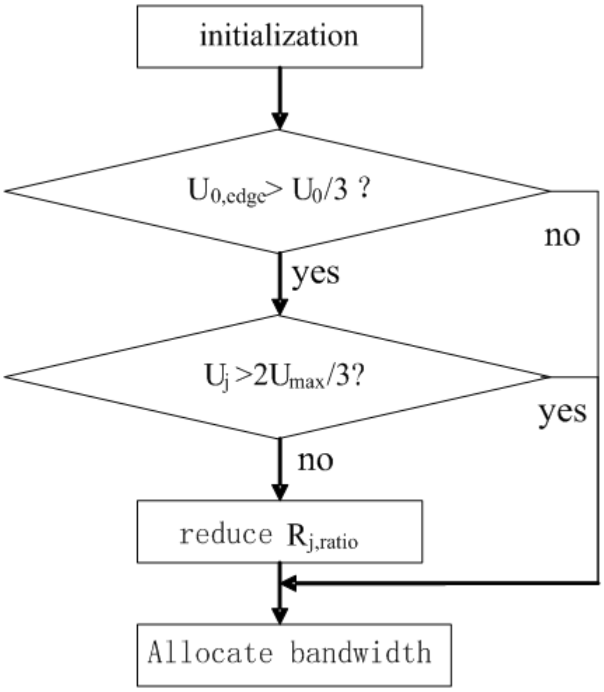

FIGURE 4. Improving the CEUs throughput by modifying radius ratio

CIU is allocated S_2 and S_3 with lower transmission power, while the cell edge is allocated S_1 with higher transmission power in the reference cell.

3. **Proposed Algorithm.** Analysis model: for simplicity, we divide the cell into several annular zones as in Fig.2, and due to the symmetry of the system, we assume the users in each zone have the same modulation and code scheme. According to SFR, when the radius of the inner area is given $r_{inner-cell} = \lambda \cdot R$ $(0 \leq \lambda \leq 1)$ there will be a SIR distribution in inner cell and edge cell respectively.

$$\begin{aligned} SIR_{inner-cell} &= f_{inner}(r_{inner-cell}) \\ SIR_{edge-cell} &= f_{edge}(r_{edge-cell}) \end{aligned} \tag{1}$$

Then, the inverse function can be easily got

$$\begin{aligned} r_{inner-cell} &= {f_{inner}}^{-1}(SIR_{inner-cell}) \\ r_{edge-cell} &= {f_{edge}}^{-1}(SIR_{edge-cell}) \end{aligned} \tag{2}$$

From the above formula and the mapping relation between the SIR and the modulation and code rate from 3GPP, as shown in table 1, the range of each annular zone could be easily obtained, as shown in Fig.2. In each annular zone, the modulation and coding scheme is same. We define every annular zone in the inner areas and the corresponding area as $A^m_{inner-cell}$ and $S^m_{inner-cell}$, m=0,1,..,7, and the ones in the edge areas as $A^n_{edge-cell}$ and $S^n_{edge-cell}$, m=0,1,..,7, respectively. $m = 0 (n = 0)$ represents the channel condition too bad to demodulation in this area, which usually happens at the cell edge when frequency reuse factor of 1 is used. There may be no such a zone especially at the cell edge if reuse3 is used, in which the area of this zone defined as 0.

Consider uniform distributed user, the throughput of each user in every annular zone of the inner cell is

Table 1. The mapping between SIR and modulation and coding scheme

m	Modulation	Coding rate	SIR(dB)
0	N/A	N/A	<4.5
1	QPSK	1/4	4.5
2		1/2	7.5
3		3/4	11
4	16QAM	5/8	16.5
5		3/4	18
6	64QAM	5/8	22.28
7		3/4	23.78

$$T_{inner-cell}^{m,u} = \frac{b_m \times C_m \times subcarrier}{T_{ofdm}} \tag{3}$$

Where, b_m is the transmitted bit in every sub-carrier when user located in annular zone m, C_m is the used code rate in annular zone m. The probability distribution of each inner-user located in every annular zone could be got.

$$P\left(A = A_{inner-cell}^{m}\right) = \begin{cases} \frac{S_{inner-cell}^{m}}{S_{inner-cell}} = \frac{\left(r_A^1\right)^2}{r^2{}_{inner-cell}}; m = 1,\ r_A^m \le r_{inner-cell} \\ \frac{S_{inner-cell}^{m}}{S_{inner-cell}} = \frac{\left(r_A^m\right)^2 - \left(r_A^{m-1}\right)^2}{r^2{}_{inner-cell}}; m \ne 1,\ r_A^m \le r_{inner-cell} \\ 1; m = 1,\ r_A^m > r_{inner-cell} \\ \frac{S_{inner-cell}^{m}}{S_{inner-cell}} = \frac{r_{inner-cell}{}^2 - \left(r_A^{m-1}\right)^2}{r^2{}_{inner-cell}}; m \ne 1,\ r_A^m > r_c, \\ r_A^{m-1} \le r_{inner-cell} 0; m \ne 1,\ r_A^{m-1} > r_{inner-cell} \end{cases} \tag{4}$$

Where, r_A^m is the distance from base station to cingulum m, as is shown in Fig.2. Similarly, the probability distribution of each edge-user located in every annular zone could be obtained, denoted as $P\left(B = B_{edge-cell}^{n}\right)$.

$$P\left(B = B_{edge-cell}^{n}\right) = \begin{cases} 0\ ; n = 1,\ r_B^n \le r_{inner-cell} \\ \frac{S_{edge-cell}^{n}}{S_{edge-cell}} = \frac{\left(r_B^1\right)^2 - r^2{}_{inner-cell}}{R^2 - r^2{}_{inner-cell}}\ ; n = 1,\ r_B^n > r_{inner-cell} \\ \frac{S_{edge-cell}^{n}}{S_{edge-cell}} = \frac{\left(r_B^n\right)^2 - r^2{}_{inner-cell}}{R^2 - r^2{}_{inner-cell}}\ ; n \ne 1,\ r_B^n > r_{inner-cell}, \\ r_B^{n-1} \le r_{inner-cell} \\ \frac{S_{edge-cell}^{n}}{S_{edge-cell}} = \frac{\left(r_B^n\right)^2 - \left(r_B^{n-1}\right)^2}{R^2 - r^2{}_{inner-cell}}\ ; n \ne 1,\ r_B^{n-1} > r_{inner-cell} \end{cases} \tag{5}$$

Then, the average throughput of every user in inner cell is

$$T_{inner-cell}^{u} = \sum_{i=0}^{m} P(A = A_{inner-cell}^{i}) \times T_{inner-cell}^{i,u} \tag{6}$$

$$T_{edge-cell}^{u} = \sum_{i=0}^{n} P(B = B_{edge-cell}^{i}) \times T_{edge-cell}^{i,u} \tag{7}$$

We assume each user is allocated a subband, therefore, the available frequency resource of inner cell and edge cell could be valued as the allowed maximum user of inner part and edge part. Assume the total user is U= 27 in the cell, the allowed maximum user of inner

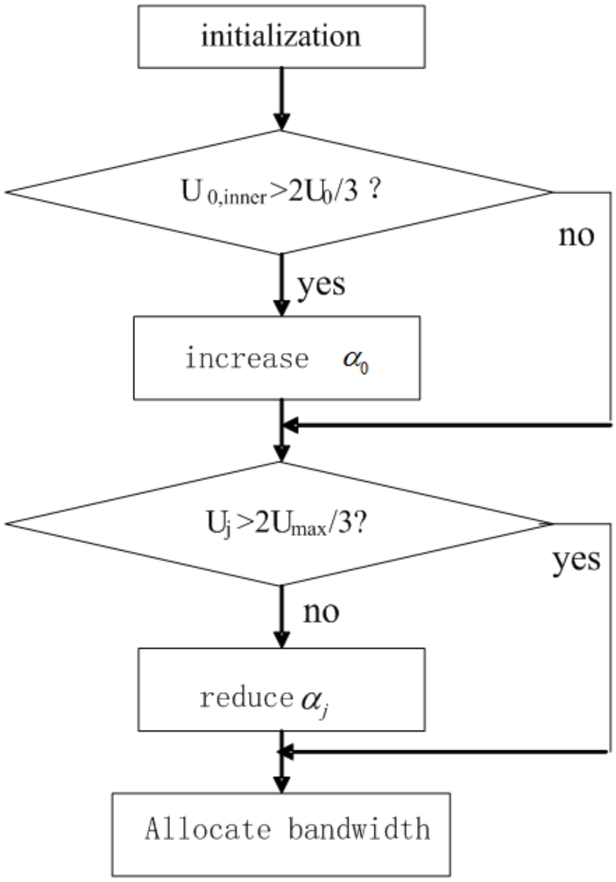

FIGURE 5. Improving the CIU's throughput by modifying power ratio

area and edge area are $U^{\max}_{inner-cell}$ and , $U^{\max}_{edge-cell}$ respectively. Therefore, we could get the probability of $U_{inner-cell}$ users in inner cell as

$$P(u = U_{inner-cell}) = C_U^{U_{inner-cell}} (p_{inner-cell})^{U_{inner-cell}} (1 - p_{inner-cell})^{U - U_{inner-cell}} \quad (8)$$

Where $p_{inner-cell}$ denotes the probability that the user is located in the inner area and it is calculated as: $p_{inner-cell} = S_{inner-cell}/S \;\; = r^2_{inner-cell}/R^2$. From (9) and (11), the overall average throughput of all users in inner cell is

$$T_{inner-cell} = \sum_{U_{inner-cell}=0}^{27} P(u = U_{inner-cell}) \times T^u_{inner-cell} \times \min(U_{inner-cell}, U^{\max}_{inner-cell}) \quad (9)$$

Similarly, the overall average throughput of all users in edge cell is

$$T_{edge-cell} = \sum_{U_{inner-cell}=0}^{27} P(u = U_{inner-cell}) \times T^u_{edge-cell} \times \min(U_{edge-cell}, U^{\max}_{edge-cell}) \quad (10)$$

Where $U^{\max}_{inner-cell} = 18, U^{\max}_{edge-cell} = 9, U_{edge-cell} = 27 - U_{inner-cell}$. So, the total average throughput of the whole cell is

$$T = T_{inner-cell} + T_{edge-cell} \quad (11)$$

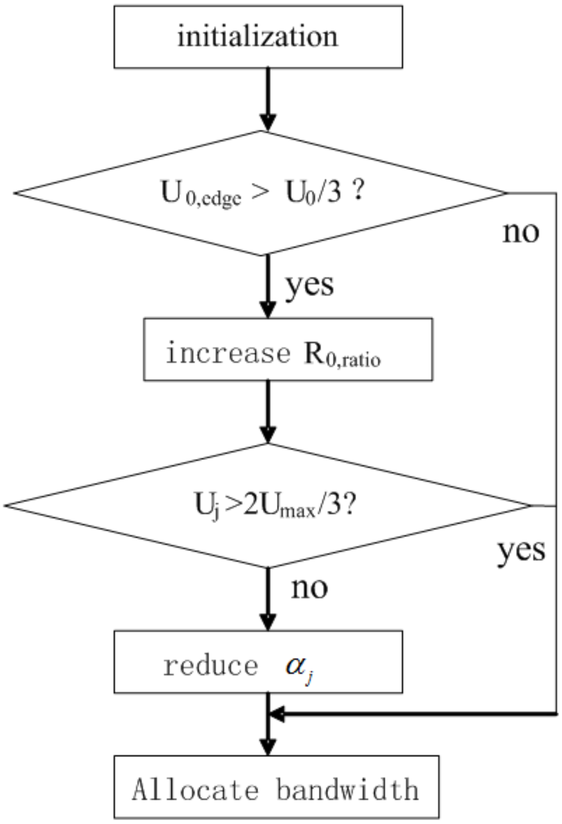

FIGURE 6. Improving the CEU's throughput by modifying power ratio

4. **Dinamic Resources Allocation.** Since the service distribution in each cell is dynamically variant with time, the dynamic resources allocation scheme are needed so as to improve the cell throughput. In the SFR scheme, besides the traditional resources unit as bandwidths, another two parameters also can be modified to change the resources allocation, i.e. power ratio and radius ratio. In this section, we will analyze the dynamic resources allocation method from the three aspects: radius ratio, power ratio and bandwidth.

4.1. **Dynamic modification of radius ratio.** When the service load in the area of cell edge is small and the service load in the area of inner cell is large, it is needed to improve the throughput in the inner cell, which can be improved by increasing the radius ratio. We assume that the user obeys to the uniform distribution. The throughput of the inner cell increases with the radius ratio increased, which is for two reasons. On the one hand, the number of CIU increases due to the increase of the radius ratio. On the other hand, the number of CEU decreases, results the smaller subbands in cell edge, which may reduce the interference to the CIU in the in adjacent cell. Therefore, the system throughput can be improved by the two factors, i.e. the increased available spectrum resources and the reduced interference. The algorithm can be realized as shown in Fig.3.

When the service load in the cell edge area of the target cell is relatively large, the target cell edge throughput can be improved by reducing the radius ratio of the ajacent cell. The algorithm can be realized as shown in Fig.4.

4.2. **Dynamic modification of power ratio α_0.** In the SFR, the transmission power for inner cell and edge cell is different. The ratio of the transmission power for inner cell to the transmission power for edge cell, thereafter called power ratio, can be adjusted to

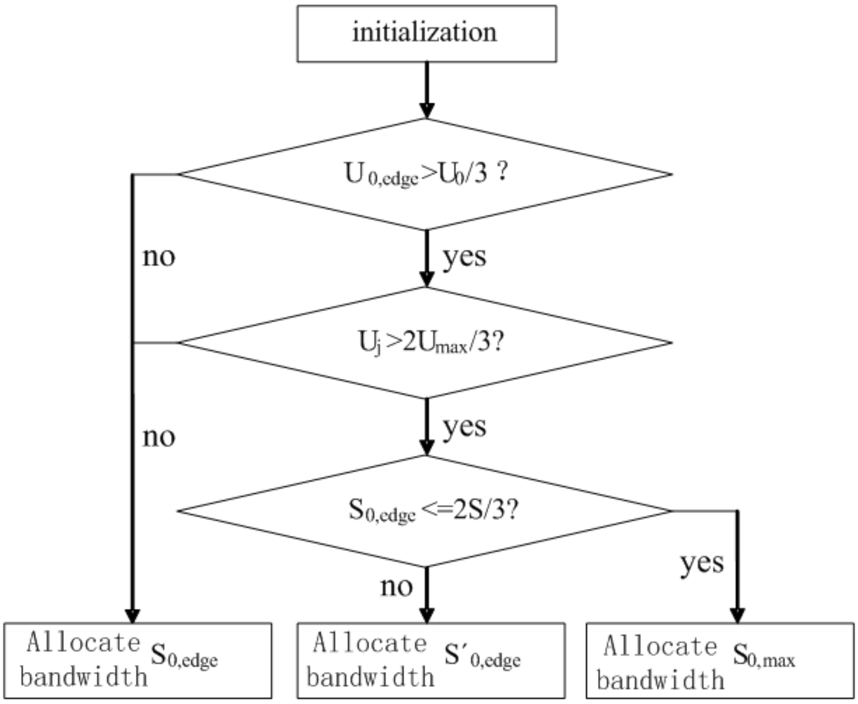

Figure 7. improving the CEUs throughput by dynamic resources allocation

improve the throughput of CIU and CEU. Specifically, The algorithm for improving the throuput of CIU by modifying power ratio can be realized as shown in Fig.5.

The algorithm for improving the throuput of CEU by modifying power ratio can be realized as shown in Fig.6.

4.3. **Dynamic modification of bandwidth.** The transmission rate of the CEU can be improved by dynamic bandwidth allocation. Let S denotes the total subbands, η denotes the ratio of the CEU service demands to the total service demands in the cell. The available subbands for CEU can be calculated as $\eta \cdot S$,which should not be larger than 66.67% for the purpose of guaranteeing the CIU's basic service demands.

5. **Results and analysis.** In this section, we will give some simulation results to verify our analysis model. In the simulation, we assume that each user experiences the worst interference, i.e. users who have been allocated the subbands will be interfered by all possible interfering cells in two tiers networks. As known from 3GPP TR25.814, the maximum transmit power is 49dBm when system bandwidth is 20MHz. Other simulation parameters are shown in table 2 as follows.

In Fig.8, the performance of the throughput of the inner cell to radius ratio is illustrated, in which, the analysis results and the simulation results are presented by dashed line and solid line separately. It can be seen that the results obtained by analysis and simulation agree well, which demonstrates the accuracy of our analysis. It also can be seen that the throughput in the inner cell isnt always increased. The reason is when the radius ratio increased, the number of users located at the edge of the inner cell, which couldnt work normally due to the serve interference from other cells, will be increased with the higher probability.

In Fig.9, the performance of the throughput of the edge cell to radius ratio is illustrated, in which, the analysis results and the simulation results are presented by dashed line and solid line separately. It can be seen that the throughput in the edge cell is decreased

Table 2. Simulation parameters

Parameters	Values
The system bandwidth	20MHz
FFT	2048
Subcarrier interval	15KHz
Symbol time	66.67us
Cyclic prefix	4.7us
OFDM symbol	71.37 us
Subband number	27
Subcarrier in each subband	48
Cell radius	1km
Modulation and code rate	QPSK(R=1/4,1/2,3/4)
	16QAM(R=5/8,3/4)
	64QAM(R=5/8,3/4)
Subband allocated for each user	1
BS maximum transmit power	49dBm
Path loss model	128.1+37.6log10(r),r(km)

strictly monotonously, because the number of CIU in other cell is also increased with the augment of the radius ratio, which will create more severe interference to CEU of the reference cell.

In Fig.10, the performance of the throughput of the whole cell to radius ratio is illustrated, in which, the analysis results and the simulation results are presented by dashed line and solid line separately. It also can be seen that when the power ratio is different, the radius ratio corresponding to the maximum throughput of the cell is also different.

The variations of CIU and CEU's throughputs with the radius ratio are shown in Fig.11 and Fig.12 respectively. It can be seen that the CIU' throughput can be improved by increasing service cell's radius ratio or reducing adjacent cell's radius ratio. The CEU' throughput can be improved by reducing adjacent cell's radius ratio.

From Fig.13 and Fig.14, it can be seen that the CIU' throughput can be improved by increasing service cell's power ratio or reducing adjacent cell's power ratio. The CEU' throughput can be improved by reducing adjacent cell's power ratio.

The CEU's throughput and total throughput under static bandwidth allocation and dynamic bandwidth allocation are shown in From Fig.15 and Fig.16 respectively.

6. **Conclusions.** In this paper, an analysis model is proposed for OFDMA-based inter cell interference, in which, all the throughput factors are considered including the inner cell throughput, the edge cell throughput and the whole cell throughput. Theoretical analysis and simulation results show that the proposed method can be utilized.

Acknowledgement. This work was partially supported by the National Natural Science Foundation of China (Grant No. 61272262), the National Science Foundation for Young Scientists of Shanxi Province, China (Grant No. 2014021021-2) and the Doctor Start Foundation of TYUST, China (Grant No. 20122032).

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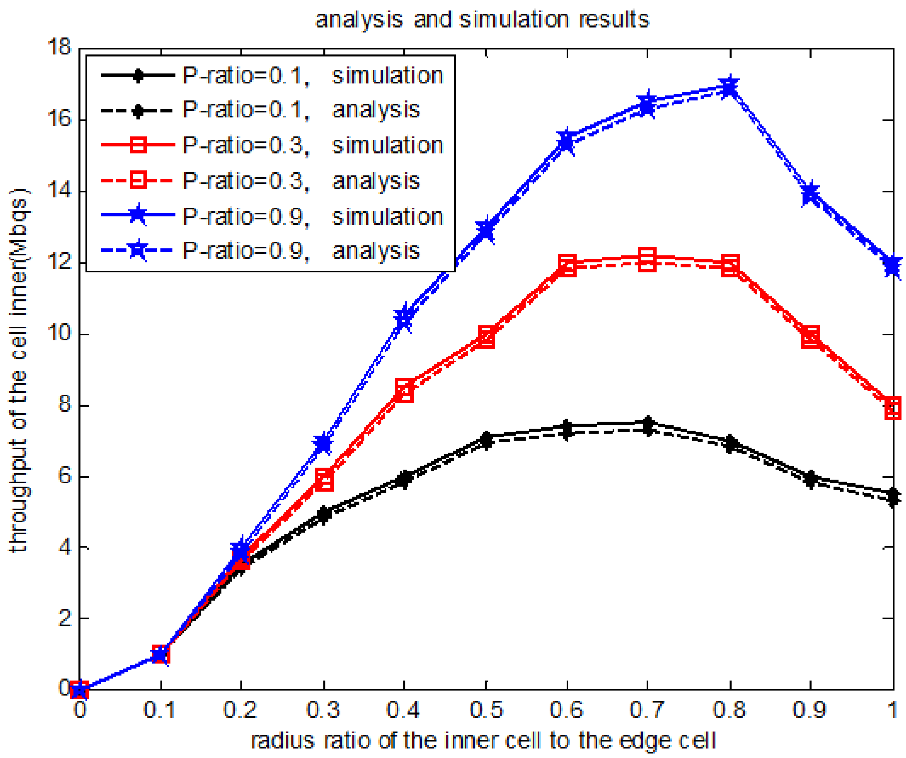

FIGURE 8. Throughput of the inner cell vs. radius ratio with analysis results (solid lines) and simulation results (dashed lines)

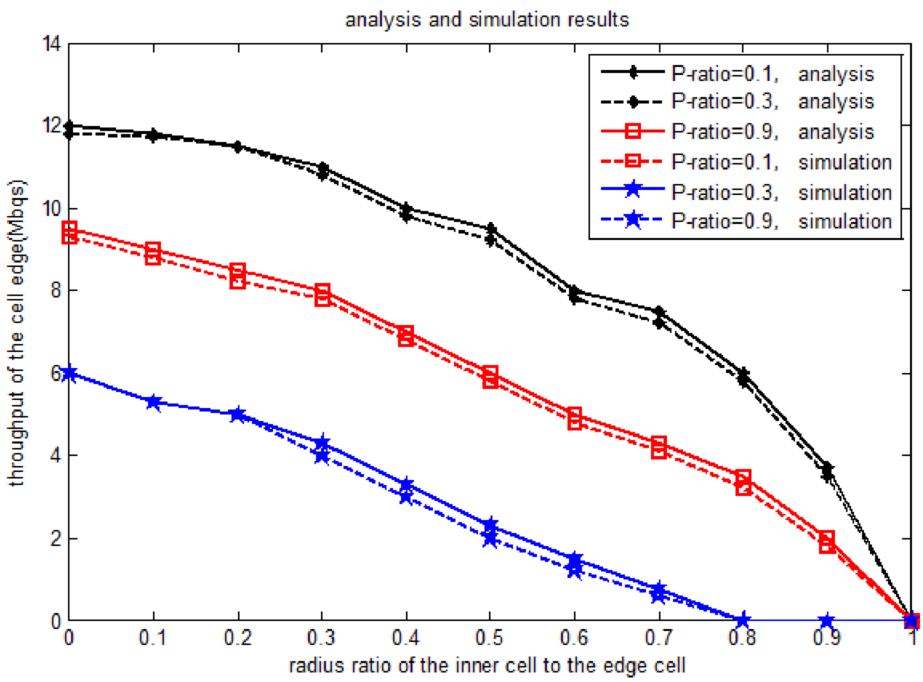

FIGURE 9. Throughput of the edge cell vs. radius ratio with analysis results (solid lines) and simulation results (dashed lines)

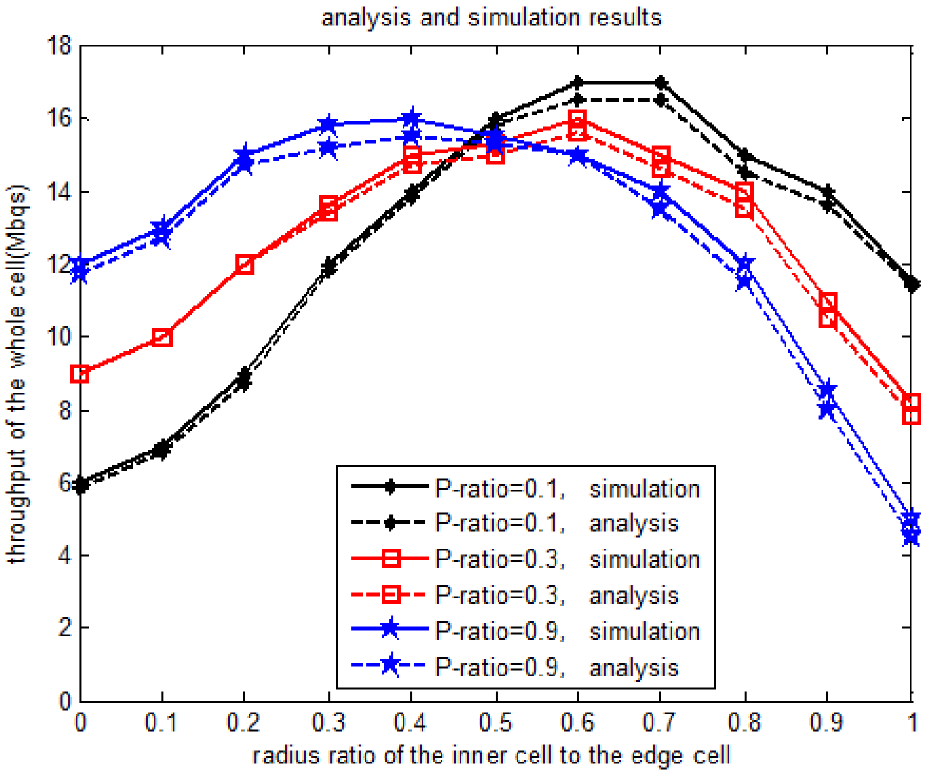

FIGURE 10. Throughput of the whole cell vs. radius ratio with analysis results (solid lines) and simulation results (dashed lines)

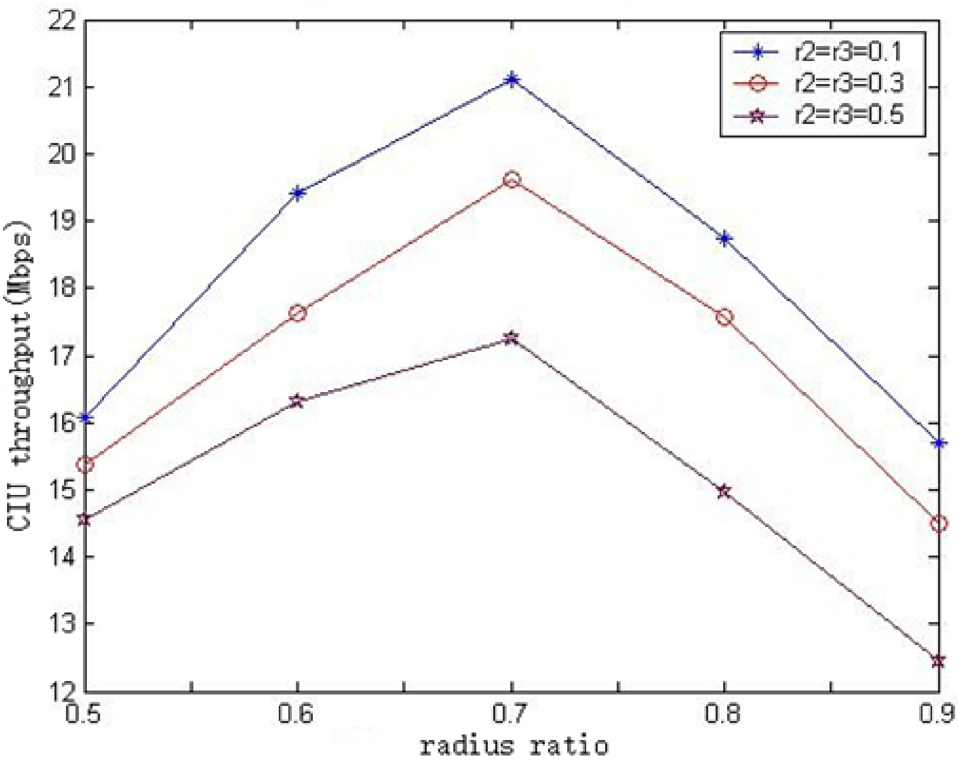

FIGURE 11. The CIU throughput vs. radius ratio

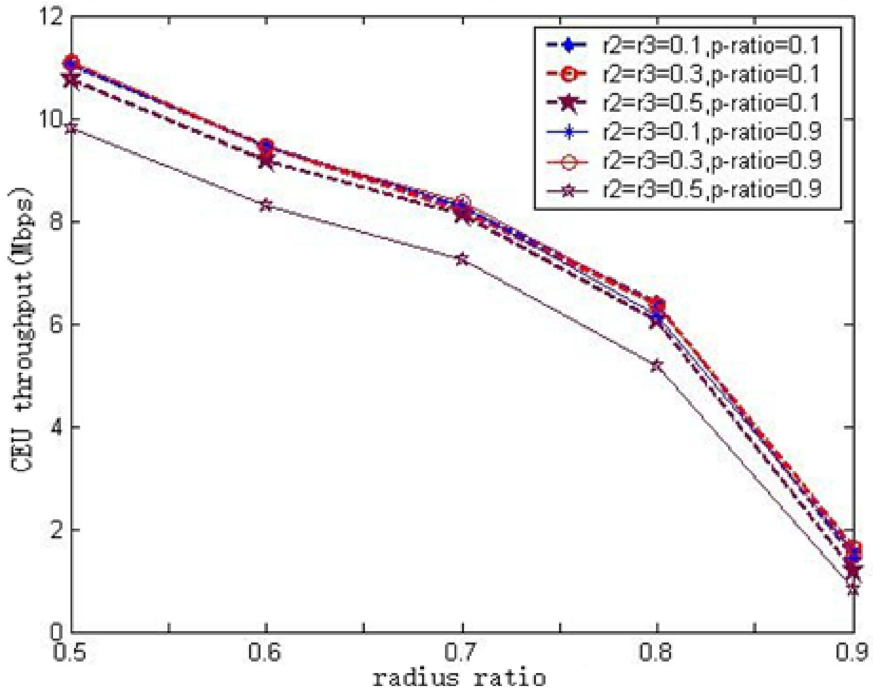

FIGURE 12. the CEU throughput vs. radius ratio

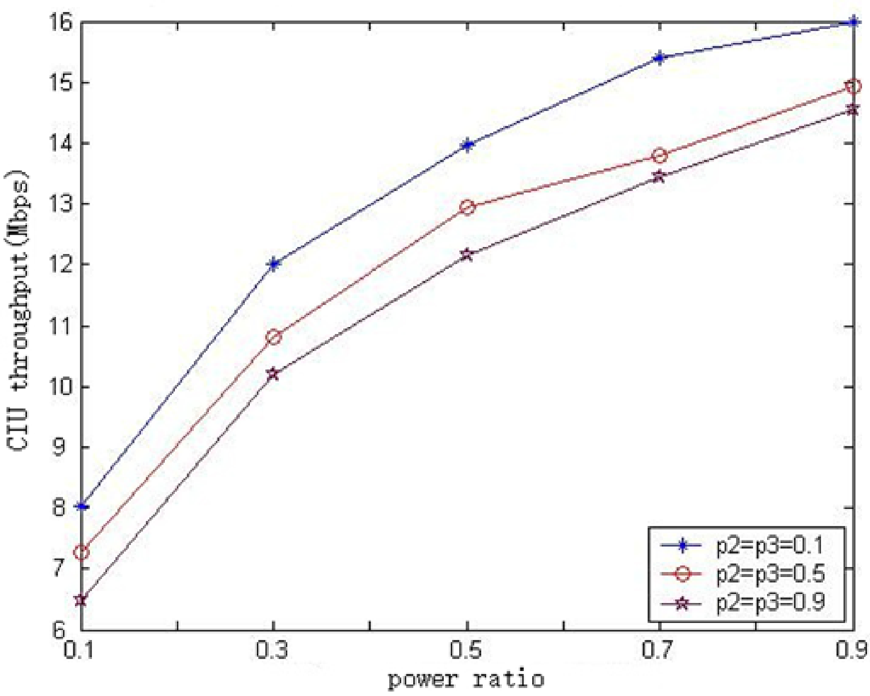

FIGURE 13. The CIU throughput vs. power ratio

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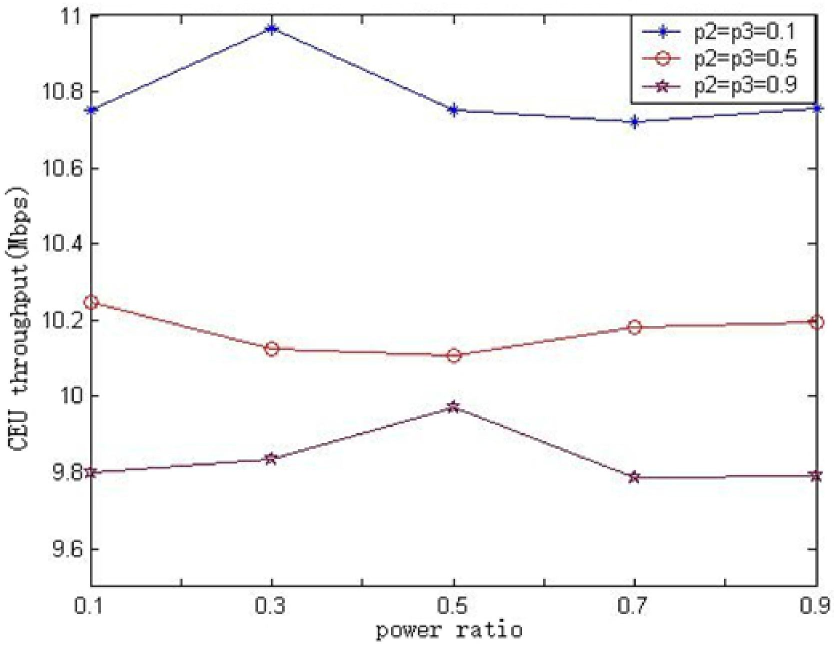

Figure 14. The CEU throughput vs. power ratio

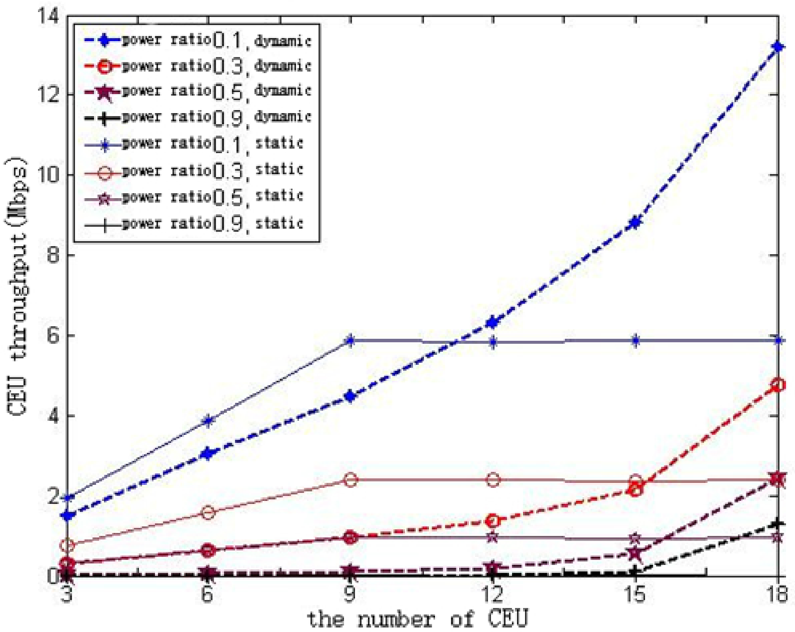

Figure 15. The CEU throughput under dynamic bandwidth allocation

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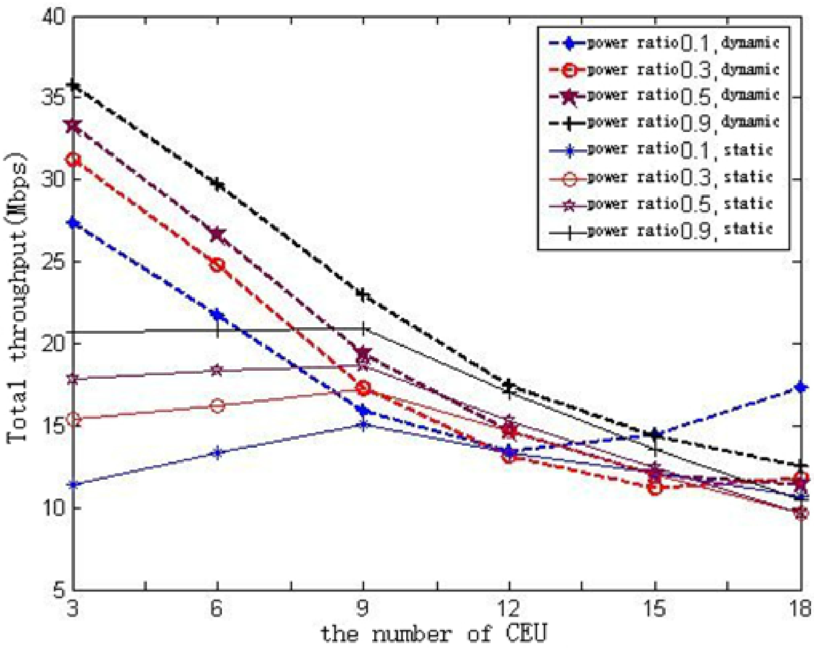

Figure 16. The system throughput under dynamic bandwidth allocation

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